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Efficient Grid-Based MANET Routing Protocol

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***Abstract*— We propose a new reliable MANET routing protocol which uses a logical two dimensional grid. The proposed protocol is called Efficient Grid-based Routing Protocol (E-GRP). E-GRP is based on the GRID routing protocol [1]. The main new features of E-GRP compared to GRID is the ability to work with different cell sizes by giving approximately same results in term of average end-to-end delay, number of overhead packets and delivery ratio in different cell side lengths. It does that by resolving path disconnected problem in grid-based routing protocols. E-GRP also has an efficient election approach comparing to GRID routing protocol. Simulation results show that E-GRP outperforms GRID in terms of average end-to-end delay and delivery ratio for different cell sizes.**

***Index Terms*— Ad-Hoc, MANET, Routing and E-GRP**

I. INTRODUCTION

A Mobile Ad-hoc Network (MANET) is defined as a collection of autonomous mobile nodes which communicate with each other in the absence of access points. A MANET is an attractive type of networks where any group of nodes can communicate anywhere without any network infrastructure. A node in a mobile ad-hoc network works as a host and as a router to serve multi-hop communication and usually has limited power resources. Routing in a mobile ad hoc network is a challenging task since the network's topology changes frequently due to mobility. A node sends control packets to discover destinations and to establish and maintain routes. Since the overall available bandwidth and power are limited, the routing-related control messages should be minimized. Therefore, route establishment by the routing protocol should be done with minimum overhead messages and minimum usage of energy and bandwidth

Many routing protocols have been proposed for MANETs such as topology-based routing protocols (e.g., DSDV, AODV and DSR), position-based routing protocols (e.g., Compass and Greedy) and grid-based routing protocol (e.g., GRID, EC-GRID) [2]. The topology-based MANET routing protocols suffer from low scalability because of the high number of overhead messages and high network latency, especially with high node mobility. The availability of cheap instruments for estimating the position of nodes in a network, like Global Positioning System (GPS) receivers, motivated many researchers to study position-based routing protocols [3], [4], [5]. The position-based routing protocols eliminate the need to maintain routes. They use the knowledge of the nodes locations to route packets. Position-based protocols assume that any node is aware of its position, the position of its neighbors and the position of the destination. The node can discover its position using a location mechanism such as Global Positioning System (GPS) [6]. It can discover its neighbors' locations by using periodic messages. The nodes use location services to discover destination nodes locations [7]. In position-based routing protocols, each node has an id and a current geographic position. Typically in grid-based routing protocols, the physical area is divided into a logical two-dimensional (2D) grid. The logical 2D grid structure allows using cell-by-cell routes where there is a cell-head node in each cell to handle routing. Cell-based routing enhances the scalability of the routing protocol [1]. One node is elected as a cell-head in each grid cell and it has the following responsibilities: (1) forward route discovery requests to its neighbor cells; (2) propagate data packets to neighboring cells; and (3) maintain the routes that pass through its cell.

Each of the three types of existing routing protocols topology-based, position-based and grid-based has weaknesses. Topology-based protocols generate a large amount of traffic when the network topology changes frequently due to mobility [6]. Position-based protocols suffer from a local minima problem which leads to non-guaranteed message delivery [8]. Furthermore, position-based protocols mostly depend on location services [6] such as Home Agent [9] and Grid Location Service [7] to discover geographical locations of destinations. Another limitation of existing grid-based routing protocols is that they use an election approach which leads to high number of control packets and end-to-end delays.

In previous grid-based routing protocols such as GRID [1] and EC-GRID [10], a mobile node sends a BID packet when it leaves a cell and enters another one. This BID packet is used to compete for the cell-head position in the new cell. In the GRID protocol, the cell-head of a cell sends a GATE message to tell any new nodes entering the cell that it is the current cell-head. Whereas in the EC-GRID protocol, the BID packet contains the node's level of energy used to compete for the cell-head position. If it has a lower level of energy, there will be no action and it goes to silent mode while if it has a higher level of energy, it takes over the position of cell-head of its cell.

The election mechanism in the previous GRID and EC-GRID grid-based routing protocols starts when the cell-head leaves a cell and enters another one. The cell-head, in this case, broadcasts a RETIRE packet which should be received by all nodes in its previous cell. After receiving a RETIRE message, all mobile nodes start broadcasting BID messages to compete for a cell-head position. A node which is closest to the center of the cell (GRID) or has a higher level of energy (EC-GRID) sends a GATE packet to show its new position. If there is only one node in the cell, it waits for a pre-defined amount of time and then it sends a GATE packet.

In this paper we propose and evaluate the performance of a new grid-based MANET routing protocol called Efficient Grid-based Routing Protocol (E-GRP) which address those limitation of existing grid-based routing protocols. The new protocol uses a new more efficient cell-head election approach and it accepts RREQ packets from non-neighbor cells. The new approach is based on the use of regular control packets (including route request and route reply packets) for piggybacking information needed for cell-head election as well as a special table at each node (Neighbors Table) for storing information about neighboring nodes. The new grid-based election approach provides improved average end-to-end delay, number of control packets needed to establish connections and delivery ratio compared to the original GRID protocol for different cell sizes.

In our proposed E-GRP routing protocol, we use a Neighbors Table containing all BID packets information (we call them Exit packets). All the information about neighbors in the same cell and mobile nodes that are within the transmission range of a node are stored in the Neighbors Table. The information gathered from Exit packets and other control packets such as route request (RREQ), route reply (RREP) and Error packets about control packet transmitter; all are kept in the Neighbors Table. Thus, each node will know about all nodes in its neighboring cells.

In the E-GRP protocol, we make use of the regular RREQ, RREP and Error packets to piggyback information about the sending nodes. The E-GRP protocol allows mobile nodes to use control packets from all cells even non-neighbors cells. This mechanism allows E-GRP to tolerate grid-based disconnected paths which affect the grid-based routing protocols. This mechanism described in the following section.

We have conducted a simulation-based performance evaluation of the proposed E-GRP protocol and measured the average message delivery ratio, the amount of communication overhead needed to discover and maintain routes, and the average end-to-end delay. We have extended the NS2 network simulator, which has been widely used in the literature for studying the performance of MANET routing protocols [1], [11], [12], to evaluate the performance of E-GRP and compare it with the GRID protocol. We studied the performance of E-GRP under a variety of network densities, traffic loads and cell sizes. The results show that E-GRP provides much lower average end-to-end delay and higher packet delivery ratios than GRID under these conditions.

The rest of this paper is organized as follows: Section 2 explains E-GRP structure and it also presents E-GRP route discovery and route maintenance. The Performance evaluation results are presented in section 3. Finally, we conclude in section 4.

II. E-GRP MANET ROUTING PROTOCOL

Like other grid-based protocols, E-GRP divides the physical area into a logical two-dimensional grid of equal cells as illustrated in Figure 1.

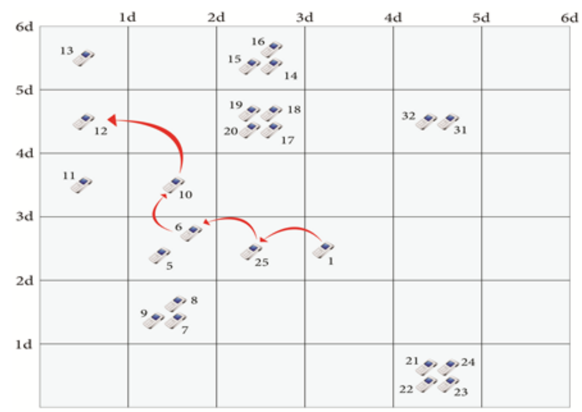


Figure 1: Logical 2D grid view of the physical MANET region

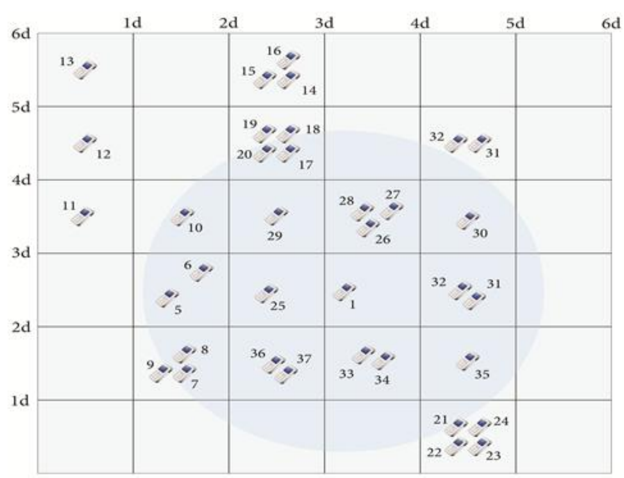


Figure 2: Neighbors of Node 1

In E-GRP, a packet travels from a source to destination by hopping from a cell to another cell without the limitation of moving to neighboring cells only which is used in other grid-based routing protocols. A selected cell-head in each cell is responsible of forwarding the packet across that cell. The union of cell-heads forms a backbone of the MANET.

The cell-head is selected as the node with highest id in a cell. Notice that, each node chooses a cell-head for a neighbor cell according to the local information it has about its neighbors. Any mobile node in a cell is a potential cell-head for its neighbor cells. Each node maintains two tables: a Neighbors Table and a Routing Table. The Neighbors Table of a node lists all its neighboring nodes. This table is structured as a group of lists.

Each list represents a neighbor cell address and lists the ids of all nodes in this cell. Consider for example the MANET of Figure 2, Table 1 shows the Neighbors Table of Node 1 located in the cell (4, 3) in this example. The cell ID field indicates the top left corner of the cell.

Table 1: Neighbors Table of Node 1 in Figure 2

Neighbors Table	
Cell ID	Node Ids
5,4	30
4,4	26, 27, 28
3,4	29
3,5	16, 20
2,4	10
3,3	25
2,3	5, 6
2,3	36, 37
2,2	7, 8
2,4	33, 34
5,2	35
5,1	21
5,3	31, 32

The node Routing Table (see Table 2) lists known location and routing information about destination cells including the following:

a) *Destination cell:* address (coordinates) of the destination cell. Each cell has an address corresponding to a pair of coordinates (row number, column number) in the 2D grid.
b) *Next cell:* the address of the next cell (next hop) towards the destination cell.
c) *Number of hops:* number of cells to cross from the current cell to the destination cell.
d) *Sequence number of the destination:* used to refresh the route table. The node Routing Table is refreshed whenever a node receives a new route request packet (see route discovery and maintenance section).

A. Control Packets

E-GRP uses control packets to maintain the Neighbors and the Routing tables. The information about neighbors is mainly obtained from (piggy-backed on) control packets. E-GRP uses five types of overhead (control) packets:

a) Route Request Packet (RREQ): A route request packet piggy-backs geographic location of the source node (sender node) to be recorded by all intermediate nodes and by the destination node. Every intermediate node will rebroadcast this packet after piggy-backing its geographic location. This information is overwritten by every RREQ re-broadcaster.

Table 2: Structure of Routing Table

Node ID	Next Cell	Destination Cell	Hops	Sequence Number
Node 5	2,1	3,5	4	30
Node 8	2,1	10,6	6	20
Node 3	3,3	6,5	3	33
Node 6	3,2	8,4	3	11
Node 15	4,3	5,10	7	2
Node 11	4,3	5,8	3	9

b) Route Reply Packet (RREP): whenever a Route Reply Packet travels on a route, it piggy-backs geographic location about the previous intermediate node.

c) Error Packet: It is sent when an intermediate mobile node loses the connection to the next hop. This packet is sent back to the source node telling it about invalidity of the current path.

d) Exit Packet: when any node moves out of its current cell to another cell, it broadcasts an Exit Packet to tell neighbors about its new location

e) RETIRE Packet: when a cell-head node moves out of its cell to another one, it sends a uincat message containg its routing table to the optional new cell-head which has the maximum id in its previous cell.

B. Route Discovery and Maintenance

Any node that decides to initiate a route discovery (if there is no information about the destination neither in the Neighbors Table nor in the Routing Table) broadcasts a route request (RREQ) to all its neighbors (all nodes within its transmission range). A node receiving the RREQ has two possible cases:

Case 1: Cell-Head Node. A cell-head node receiving the RREQ has to send a route reply (RREP) packet back to the source mobile node if it is the destination. Otherwise, it rebroadcasts the RREQ. If any node receives a previously processed RREQ (it checks the node sequence number in its Routing Table), the node discards it and does not forward it. RREQ piggybacks the location of the previous hop node. These are used to update the Neighbors' Table.

Case 2: Non Cell-Head Node. It sends a RREP packet if it is the destination; otherwise it records the cell location information of the forwarding node and then discards the RREQ packet.

Only one node in each cell (the cell-head) participates in rebroadcasting the RREQ. This mechanism is called cell-based flooding (as opposed to total flooding used in AODV for example). The RREP propagates back to the source via the cell-head nodes). These cell-head nodes update their routing tables. Once the source node receives the RREP, it starts forwarding data packets to the destination. If the source receives a later RREP containing a greater sequence number or containing the same sequence number with a smaller hop count, it updates its routing information for that destination and begins using the better route.

C. E-GRP New Path Structure

After building the Neighbors Table with the most recent information, the selection of the cell-head node becomes simple and fast. A node with highest id is chosen as a cell-head implicitly by choosing a mobile node with highest id without any extra actions. Any cell-head that leaves its cell to another cell should forward all its routing table information to a node which has highest id in the previous cell. All other nodes should start dealing with it as the new cell-head.

There is another critical case when a node enters a cell and finds out that its id is higher than the id of the cell-head of the newly entered cell. In this case, the current cell-head should retire and send all of its routing table information to the new cell-head.

The proposed E-GRP protocol changes the approach of electing cell-heads in the grid-based routing protocol [1] by keeping all information about the neighboring nodes which were received piggy-backed on control packets. The new approach also eliminates the use of periodic control packets and it introduces unicast retiring messages.

In the previous grid-based MANET routing protocols such as GRID [1], GSRA [13] and ECGRID [14] the path is constructed by cell-heads which are located in the closest neighbor cells. In other words, if a mobile node intends to establish a connection, it checks the existence of mobile node destination location information. In case of non-existence of route information, it broadcasts RREQ packet. The RREQ packets are re-broadcasted by cell-heads of neighboring cells. When the destination node is discovered, a route reply packet follows back the route path until source mobile node. The route path is established as illustrated in Figure 3 cell-by-cell.

There are some cases where this mechanism could lead to disconnect the network. For example, when two mobile nodes want to communicate and they are in different cells but not in neighboring (or adjacent) neighbor cells (Figure 4 illustrates this case). By using the original cell-to-cell GRID mechanism leads to disconnect the path. These two mobile nodes are not connected because of non-existence of intermediate nodes in the neighboring (or adjacent) cells. The RREQ packets are discarded if they are not from the neighboring (or adjacent) cells.

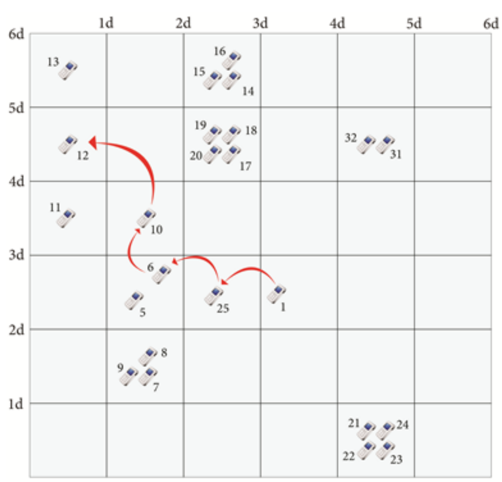


Figure 3: Established Connection Paths (Cell-by-Cell)

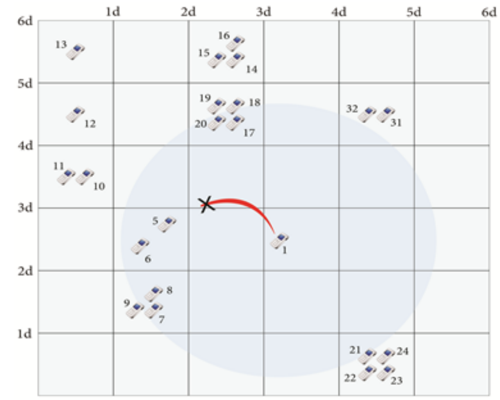


Figure 4: Non-Existence of nodes in the neighboring cells effects

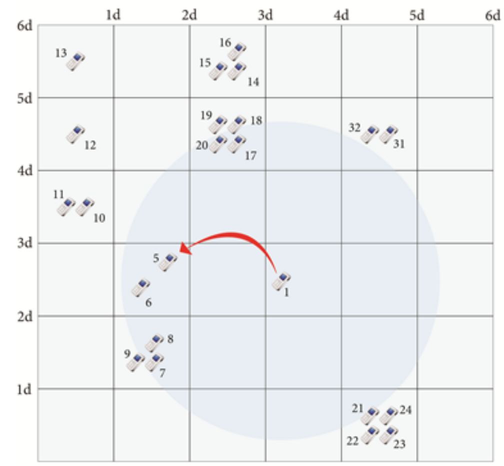


Figure 5: Established Connection Path by Jumping over Empty Cells

E-GRP solves this problem by allowing cell-heads to accept RREQ and other control packets, if they come from non-adjacent neighbors cells (Figure 5 illustrates this case).

D. Grid Cell sizes

One of the parameters that affect the performance of grid-based routing protocols is the cell size. The packet should travel from one cell to another (cell-to-cell). Different cell sizes result in big differences in the performance parameters (delivery ratio, number of control packets and average end-to-end delay). We assume a fixed and identical transmission range (r) for all MANET nodes. For a given transmission range (r); several cell sizes could be used to allow cell-heads to establish paths. In previous studies of grid-based routing protocols, the authors proposed different cell sizes. Typically used cell sizes are *d1*, *d2* and *d3* given by:

$$\mathrm{d1} = \frac{\mathrm{r}}{2\sqrt{2}}, \ \mathrm{d2} = \frac{\sqrt{2}\mathrm{r}}{3} \ \text{and} \ \mathrm{d3} = \frac{2\mathrm{r}}{\sqrt{10}}.$$

1- $d1 = \frac{r}{2\sqrt{2}}$: using this size allows a cell-head in a cell to communicate with any mobile node in any of the eight surrounding cells (see Figure 6).

2- $\mathrm{d2} = \frac{\sqrt{2}\mathrm{r}}{3}$: using this size allows a cell-head which is close to the center of a cell to communicate with all nodes in the eight surrounding cells (see Figure 7).

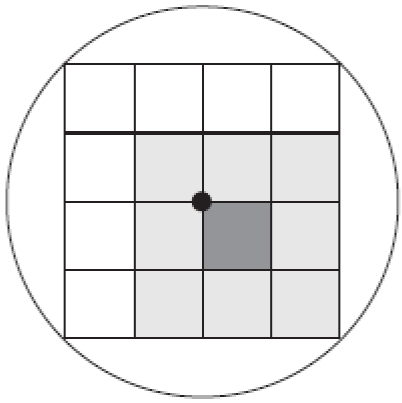


Figure 6: cell size is $d1 = \frac{r}{2\sqrt{2}}$

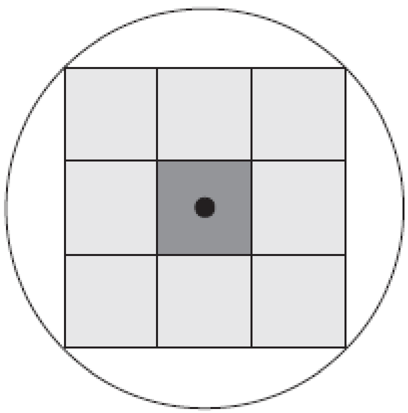


Figure 7: cell size is $d2 = \frac{\sqrt{2}r}{3}$

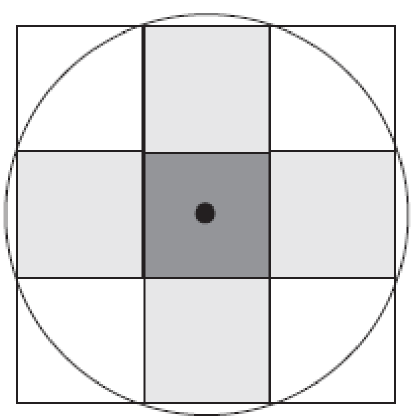


Figure 8: cell size is $d3 = \frac{2r}{\sqrt{10}}$

3- $d3 = \frac{2r}{\sqrt{10}}$: this size will allow a cell-head which is close to the center of a cell to communicate with all nodes in the four surrounding other than the diagonally adjacent cells (see Figure 8).

In this paper, we study the effect of different cell sizes on the protocol performance and we propose a new mechanism that leads to reduce this effect. We do that by accepting any RREQ request even if it is from non-adjacent neighbor cells. These could lead to have minimum number of hops. E-GRP is evaluated using an extended NS-2 simulator under varying network density, traffic load and node mobility conditions for a variety of cell sizes.

III. Performance Evaluation

A. *Assumptions*

This section reports results from extensive simulation experiments that have been conducted to evaluate the performance of the proposed E-GRP protocol. The following assumptions have been used throughout these simulation experiments:

- All nodes are homogenous and have a fixed transmission range which is 300 meters.
- Each node has a sufficient energy level to function throughout the simulation time.
- The wireless transceivers are active all the time.
- Each node participating in the MANET is willing to forward packets for other nodes in the network.
- Each cell in the logical 2D-grid has a unique id. We use the grid cell coordinates as a cell id.
- Each node has a GPS receiver which is used to get its geographical location. Each node is aware of its geographical location and to which cell it belongs.
- The simulator runs for a given fixed time.

We simulated E-GRP using an extended NS-2network simulator. The simulation parameters are shown in Table 3.

Table 3: Simulation Parameters

Simulation Parameters	
Communication type	CBR
CBR sending rate	4 packets per second
Simulation area	1000m x 1000m
Simulation protocols	GRID, E-GRP
Mobility model	Steady-state random waypoint
Number of nodes	20, 40, 60, 80
Nodes average speed	2 (meters/second)
Average pause time	2 , (Delta =1 seconds)
Number of sender-receiver connections	2, 4, 6, 8,10
Transmission range	300 meters
Physical link bandwidth	11 Mbps
Number of simulation trials	40 times
Simulation time	1000 Seconds
Cell sizes: *d1, d2 , d3*	*d1=106, d2=141, d3=190*

B. *Steady-State Random Waypoint Mobility Model*

There is a steady-state convergence problem in the normal random waypoint mobility model. This problem is known in the literature as the stationary distribution problem [15]. The steady-state convergence of nodes in the random waypoint mobility model is reached after some simulation time. This leads to substantial differences between routing protocol performance measures taken early during a simulation and measures taken later in the simulation [16]. The primary method for dealing with this problem is to discard the initial sequence of observations. The authors of [17] suggest that discarding 1000 seconds of simulation time will ensure that the initialization problem will be removed. This suggestion is difficult to be applied because one cannot easily know the length of the sequence that needs to be discarded. The authors of [15] solve this problem by deriving initial parameters for the simulator with stationary distribution of location, speed and pause time.

There are three known implementations for random waypoint mobility mode in NS-2:

- setdest: starts the simulation by putting all nodes in pause
- mobgen: starts the simulation with approximately half of the nodes moving from their initial location
- mobgen-ss: starts with steady-state convergence node distribution (steady-state random waypoint mobility model). We have selected this implementation in our simulations because it solves the stationary distribution problem.

C. *Performance Metrics*

We have used the following performance metrics in the conducted NS-2 simulations for comparing the performance of the proposed SE-GRP protocol and the GRID protocol:

a) Data Delivery Ratio: the ratio of the number of packets successfully received at the destinations to the total number of data packets sent during the simulation time

b) End to-End delay: the average time delay to send a packet from source to destination including all possible delays such as buffering during route discovery, queuing delays at the interface queues, retransmission delays at the MAC, and propagation and transfer delays.

D. *Simulation Results*

This section investigates the effect of accepting control packets from mobile nodes located at non-adjacent neighbor cells and the effect of replacing the previous cell-election approach of the GRID routing protocol by the new E-GRP approach.

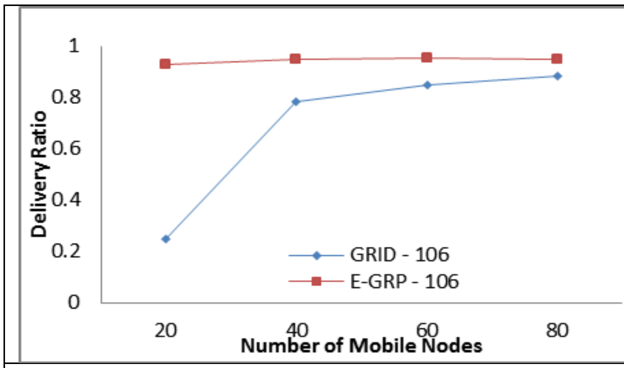
In this work we have extended an original implementation of NS-2 (version 3.4) with implementations of the two protocols GRID and E-GRP in order to evaluate and compare their performance.

The performance evaluation of E-GRP has been conducted using the simulation model and parameters outlined in Table 3. The evaluation studies the impact of the three parameters network density and traffic load d on the three performance metrics packet delivery ratio and average end-to-end delay for a variety of cell sizes.

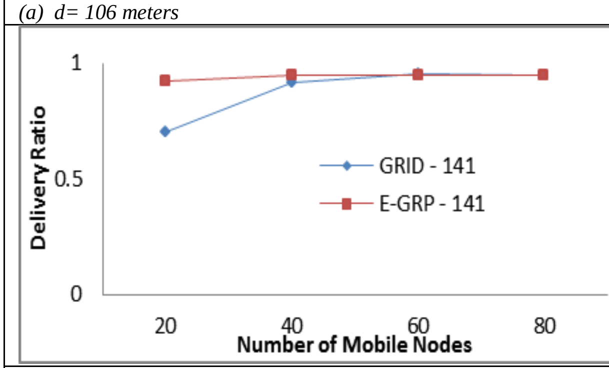
1) *Impact of Network Density*

This section presents results of studying the impact of network densisty on the performance of E-GRP comapred to GRID. The network density has been varied by deploying 20, 40, 60 and 80 mobile nodes in a fixed geographic area of dimensions 1000m × 1000m. The nodes in the network move according to the steady-state random waypoint mobility model with average speed of 2 meters per second. The number of connections between peer random sources and destinations has been fixed to 10, all established during the simulation time. Each source node in a conection sends four packets per second and each packet is of size 512 bytes.

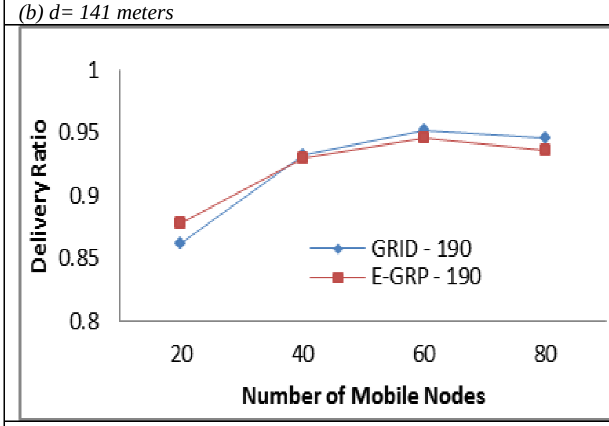
Delivery Ratio: Figure 9a reveals that when the cell size is d1, E-GRP outperforms GRID in terms of delivery ratio. When the cell size is small the GRID routing protocol has disconnected paths. But when increasing the number of mobile nodes (network density); the GRID routing protocol improves in terms of delivery ratio and becomes close to E-GRP. Furthermore, E-GRP shows stability and good performance in terms of delivery ratio. The increasing of density has no effect on the delivery of E-GRP which remains above 90%.



(a) d= 106 meters



(b) d= 141 meters



(c) d= 190 meters

Figure 9: Delivery Ratio vs. Number of Mobile Nodes for E-GRP and GRID. Mobility Speed = 2 m/s , Number of Source-Destination Connections = 10, CBR Rate= 4 p/s

Figure 9b shows that the difference in delivery ratio between GRID and E-GRP is reduced when the cell sizes is increased to d2. The E-GRP still has better behavior and stability in terms of delivery ratio. The cell sizes *d2* allows more mobile nodes using GRID to communicate with each other's with better delivery ratio.

Figure 9c shows that both protocols (E-GRP and GRID) have approximately the same delivery ratio when the cell size is *d3*. E-GRP become less stable because the cell size *d3* leads to cover transmission range of the mobile nodes.

Overall, the delivery ratio of E-GRP shows a high stability for a variety of cell sizes whereas it has significant effect on delivery ratio of the GRID routing protocol.

Average End-to-End Delay: Figure 10a reveals that E-GRP has a very efficient end-to-end delay compared to GRID routing protocol when the cell size is d1. The flexibility of choosing a path in E-GRP leads to have shortest path to destination. In the other hand, the GRID protocol does not have the E-GRP flexibility which leads to have high end-to-end delay comparing to E-GRP. In GRID routing protocol, disconnected paths lead to buffer packets which lead to increase end-to-end delay.

When the cell size is d2 (illustrated in Figure 10b), the average end-to-end delay of GRID is reduced compared to cell size d1 because of the number of disconnected paths. In the other hand, E-GRP keeps the same level of efficiency.

Figure 10c shows that the cell size d3 leads to improve the average end-to-end delay of the GRID protocol. This cell size allows GRID to overcome the problem of path disconnectivity. In the other hand, E-GRP still keeps the same efficiency as cell size d1 and d2.

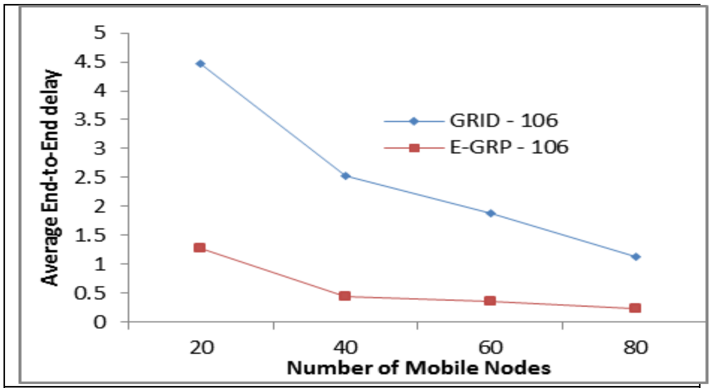
Overall, figure 10 reveals that the E-GRP has a better end-to-end delay compared to GRID routing protocol. It also shows E-GRP have stability in the end-to-end delay with change in cell size. In the other hand, GRID is significantly affected by cell side length and there is improvement in its end-to-end delay with increase of cell side length.

2) Impact of Offered Load

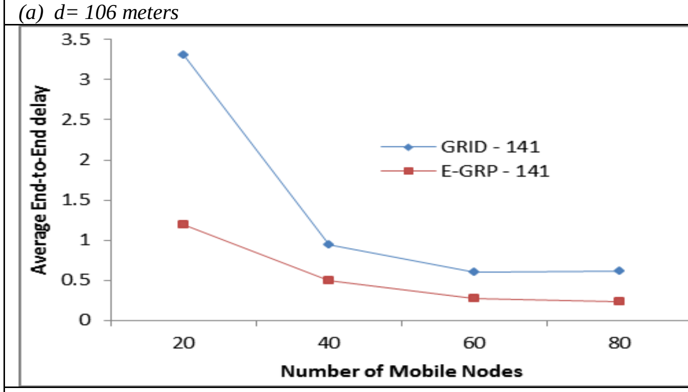
In this section, nodes are placed over a network area of 1000mX1000m and each node in the network moves according to the steady-state random waypoint mobility model with average mobility speed of 2 meters per second. To investigate the impact of variation traffic loads, injection rates corresponding to 2, 4, 6, 8, and 10 random connection pairs each generating four packets per second were used. The source and destination nodes were selected randomly in each connection.

Delivery Ratio: Figure 11a shows that the increase in the number of connection pairs does not have significant impact on E-GRP and GRID protocols using cell size of d1. In spite of that, E-GRP outperforms GRID in terms of delivery ratio for a variety of connection pairs. This is because E-GRP does not effected by disconnected paths.

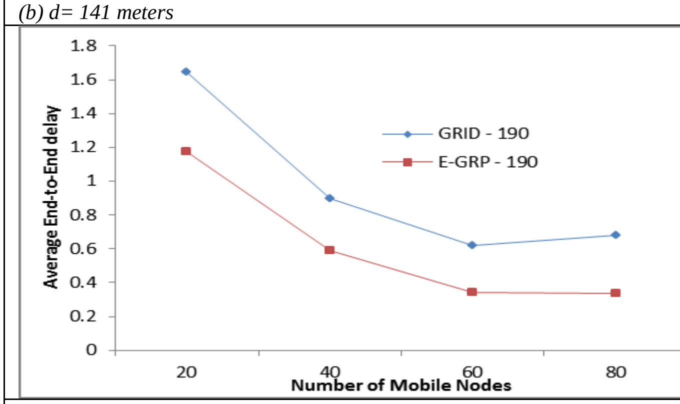
The increasing of the cell size to *d2* (illustrated at Figure 11b) improves the delivery ratio of GRID because it results in reducing the number of disconnected paths. In the other hand, using E-GRP yields approximately the same delivery ratio as with cell size *d1*.



(a) d= 106 meters



(b) d= 141 meters

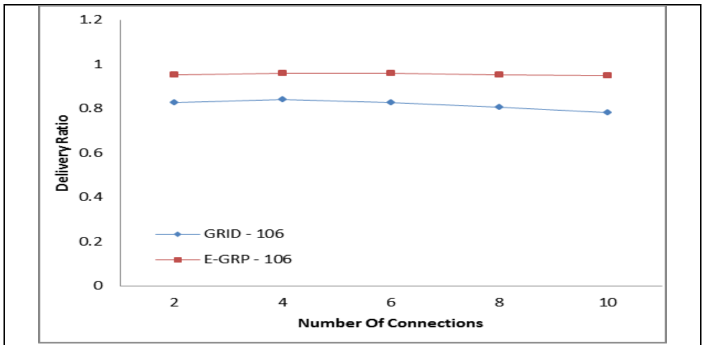


(c) d= 190 meters

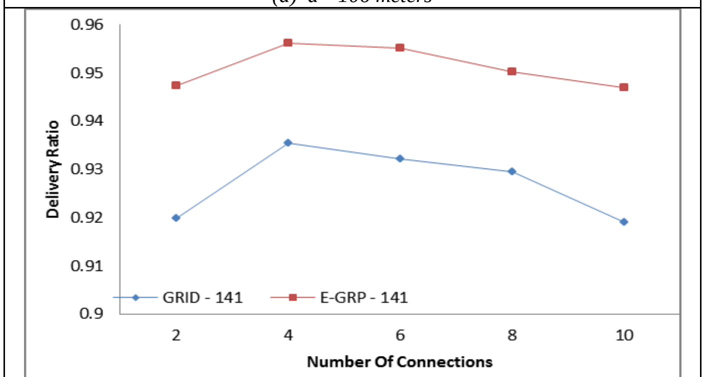
Figure 10: Average End-to-End Delay vs. Number of nodes for E-GRP and GRID. Mobility Speed=2 m/s , Number of Source-Destination Connections = 10, CBR rate= 4 p/s

Figure 11c shows that both protocols E-GRP and GRID have good delivery ratio for cell size d3. Figure 13c reveals that using cell size d3 improves the delivery ratio of GRID because when increasing cell size, the number of disconnected paths is reduced.

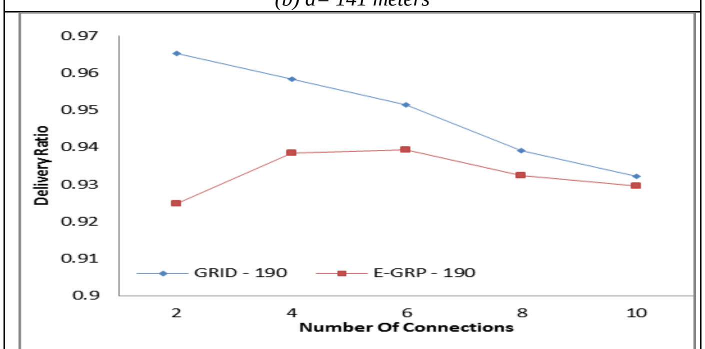
Average End-to-End delay: Figure 12a shows that E-GRP outperforms GRID in terms of average end-to-end delay when the cell size is *d1*. The improvement is over 80%. There are two reasons for this big difference, (1) the simple election approach used by E-GRP, and (2) E-GRP has shorter paths (less hops) compared to GRID. Figure 12a also shows a limited effect of the load on the average end-to-end delay in both protocols.



(a) d= 106 meters



(b) d= 141 meters



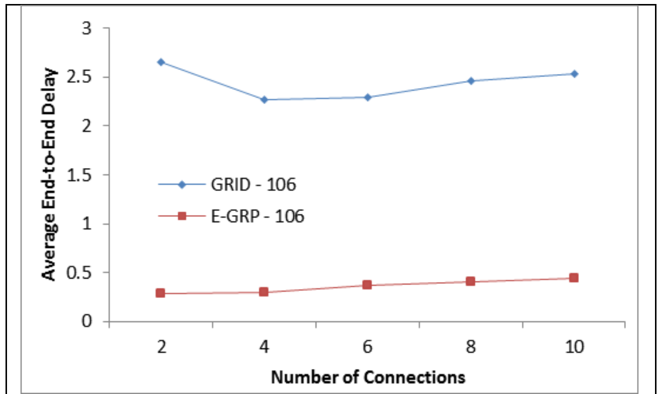
(c) d= 190 meters

Figure 11: Delivery Ratio vs. Number of connection pairs for E-GRP and GRID. Number of Nodes = 40, Mobility Speed = 2 m/s , CBR rate= 4 p/s

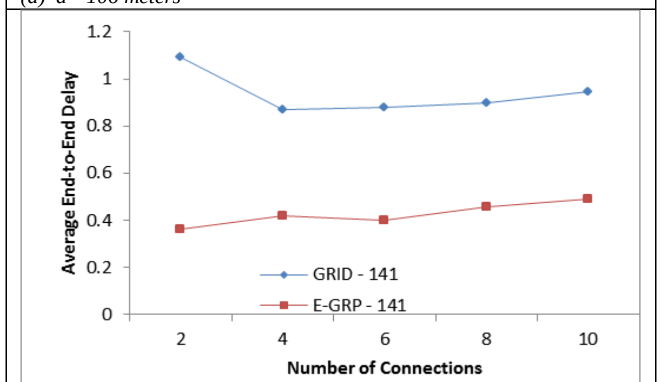
Figure 12b reveals that there is an improvement in terms of end-to-end delay for the GRID protocol when GRID routing protocol. It is about 2.6 seconds with cell size *d1* (as illustrated in Figure 12a) whereas the average delay is about 1.1 second when the cell size is *d2* with two connection pairs. In the other hand, E-GRP keeps approximately the same efficiency for both cell sizes *d1*.

There is improvement in the average delay of the GRID when the cell size is *d3* compared to *d1* and *d2* (as illustrated in Figure 12c). In the other hand, E-GRP still keeps approximately the same efficiency in both cell side length *d1* and *d2*.

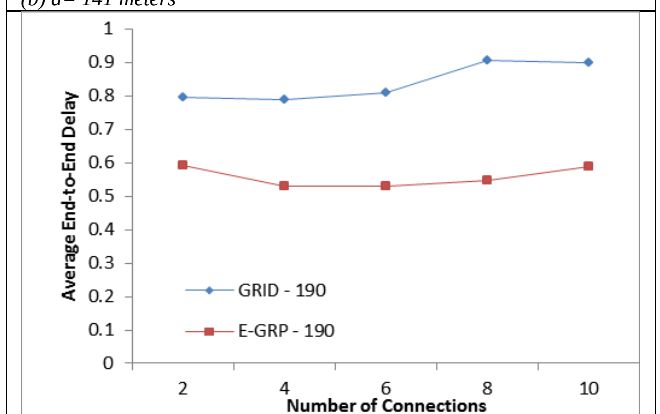
Overall, E-GRP Is More Stable When Varying The Cell Sizes Compared To GRID. GRID Has Shown A Big Difference In End-To-End Delay For Difference Cell Sizes.



(a) d= 106 meters



(b) d= 141 meters



(c) d= 190 meters

Figure 12: Number of Control Packets vs. Number of connection pairs for E-GRP and GRID. Number of Nodes = 40, Mobility Speed = 2 m/s , CBR rate= 4 p/s

IV. Conclusion

This paper has conducted a comparative performance evaluation of a new proposed grid-based routing protocol called E-GRP and the previously known grid-based routing protocol GRID. E-GRP has a more efficient election approach and it accepts control packets from mobile nodes located in non-adjacent neighbors cells. This study has assessed the impact of network density and traffic on the delivery ratio and average end-to-end delay for different cell size. Simulation results has been obtained using an extended NS-2 simulator.

Overall, E-GRP is solving the problem of disconnected paths of grid routing protocols. E-GRP is stable with changes in cell sizes in terms of delivery ratio and average end-to-end delay. In the other hand, the GRID routing protocol is significantly affected by the cell size. The results also have shown higher delivery ratios, lower number of overhead packets and lower average end-to-end delay for increased number of nodes, node mobility speeds and number of sender-receiver connections.

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